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ABSTRACT

Cognitive science is briefly reviewed, and its implications for instructional design are discussed. The application of cognitive science to instruction requires knowledge of cognitive science, the subject content taught, and the system in which the instruction is imbedded. The central concept of cognitive science is mental representation--the description of mental entities and processes, both unconscious or automatic processes, as well as conscious problem solving and classification. Other issues which have an impact on instruction are the extent and quality of existing knowledge and self-monitoring of mental processes and structures. It is important to identify the context in which learning takes place in order to promote learning and transfer. Instructional engineering heuristics, or principles for teaching, present two challenges: (1) evaluate effectiveness of proposed principles; and (2) encourage knowledge users to learn and adapt their practices in designing and carrying out instruction. Engineering heuristics include the following: develop the correct strategy; minimize memory load; use inquiry teaching; incorporate cognitive theory into computerized tutors; recognize automatic and controlled processing skills; and teach thinking and problem-solving skills. Guidelines for vocational education involve duplication of the work environment, individualizing instruction, practice, job satisfaction, and adequate resources. The functional context approach to training emphasizes the use of materials which exist on the job and making the instruction meaningful to the user. (GDC)

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Application of Cognitive Science Principles: Instructional Heurisitcs and Mechanisms for Use

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Application of Cognitive Science Principles: Instructional Heuristics and Mechanisms for Use[1]

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1. Introductory Comments

This symposium is directly concerned with the issue of applying principles from cognitive science to instruction. This is an important issue for those of us actively engaged in developing and promoting instructional technology. It is important from the practitioner's viewpoint because teaching and schooling have been under criticism, and increased effectiveness of instruction is a primary goal everywhere. It is also important from the scientist's perspective, because in a period of shrinking research budgets demonstrable value of scientific knowledge can argue for continued support. Also, it is not a new issue to those of us concerned with theories of instruction and instructional design (e.g., Gagné & Briggs, 1979, Reigeluth, 1983). What may be new is that cognitive scientists and researchers are becoming more interested in guiding teaching because of their interest in developing automated tutors.

Applying cognitive science to instruction requires expertise in three areas. One must know cognitive science, and that is a substantial task. In addition, to apply such knowledge to teaching requires considerable knowledge of both of the content taught and the system in which the instruction is embedded. These are also substantial tasks. It is unlikely that many individuals are expert in all three areas. I consider myself far from skilled in these domains. However, with the caveat that my perspectives may be "off base" because of inexpertness, I will attempt to describe briefly what cognitive science is about, then suggest that even strongly supported cognitive principles provide only tentative guidance for arranging instruction. I will review some selected guidance for teaching that cognitive scientists have recently published, and show that similar guidance has been available for many years. I prefer to think of these as heuristics for

[1] This paper was the basis for a talk given at session 43.28 at the 1986 Annual meeting of the American Educational Research Association in San Francisco, CA.
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engineering instruction rather than principles, because of their tentative nature (Reigeluth, 1983, refers to similar assertions as "formative rules"). What seems to have been lacking, in my opinion, is systematic attention to synthesizing research knowledge, applying it and determining whether it has the desired effects on student learning. Finally I will discuss some mechanisms for application, and point out the need for directing research to provide more direct support for the guidelines.

2. Cognitive Science Principles: Where are they?

Clearly, the central concept of cognitive science is *mental representation*. For the last 25 years or so cognitive researchers have developed methods for studying mental processes in real tasks and have attempted to describe and explain them precisely. For example, processes and mental entities were examined in reading, chess and other game playing, solving problems in various areas, using language, etc.. Computer programs are used to model the entities and processing in attempts to assess the adequacy of the analysis. This work contrasts starkly with that of traditional laboratory psychology that ignored or excluded mental entities and processes, and worked with artificial laboratory tasks. The architecture of the mind has been characterized as a processing system modeled after digital computers having a sensory buffer, and working memory, and various kinds of long term storage. Mental entities like scripts, schemas, frames, images, mental models have been characterized and processes that operate on the entities, such as transformations, conjunctions, deletions, reversals, and the like, have been studied.

These analyses reveal two types of representation systems that are fundamental to cognitive science. The first is a "built-in" representation system, predominantly unconscious and automatic. For example, the visual system must create a representation of physical information, and then operate on it. The individual has no options in this. The second representation system involves problem solving and classificatory behavior, is flexible and conscious and carries out the varieties of mental functions involved in analyzing a sentence, creating an image or a mental model. There may be several sub-types of representation involved and they may be described with different degrees of explicitness. programs are used to test the completeness of the models,

and predictions are compared with human performance. The question posed for those interested in using the descriptive and explanatory principles for instruction is how adequate are the computational models that represent the mental representation systems and functions? Gardner (1985) suggests that the computational models are not adequate for describing and explaining many complex tasks at this time.

While there seems to be agreement about general conceptions and processes, at more detailed levels of analysis cognitive science theory is not in a form where there is widespread agreement on method, on a taxonomy of representations, on the language for description, etc. (Gardner, 1985). For example, research comparing how domain experts and novices approach and solve problems provide some general information that might help the design of instruction (Chi, Feltovich & Glaser, 1981). See Slide 1. Experts have much greater knowledge, it's organized around principles, and they solve the problems by determining which principles apply before attempting solution. Novices rely on surface features, are more disorganized, and try equations until one works. However, the guidance derived from this work: to use schemas used by experts in training, requires considerable "artistic" interpretation. In fact, such schemas would need to simplified considerably to match the novices' level of understanding.

Slide 1

Experts & Novices

- Novices use surface features
- Experts use principles
- Need to design toward schema

Therefore, it may be premature to expect to find either strong agreement on **cognitive principles** that might serve to guide instruction or on implementation strategies. Besides, even if there were agreement, cognitive principles are precise descriptions of processing, structuring and restructuring reported given certain conditions. There is less certainty that that processing can be brought about by instructional arrangements or rules (see Reigeluth, 1983, ch 1). This is because

such proposed rules specify teaching operations necessary to produce student learning processes. Since cognitive models are currently incomplete, ignoring variables like student interest and motives, the teaching arrangements may be insufficient. In the following sections I will summarize my understanding of the main **generalities** about cognitive functioning and then discuss the tentative nature of derivative rules for devising instruction. Recommendations from cognitive science should be made with the recognition that the issues involved in devising rules for instruction have been discussed for fifty years or more (Montague & Wulfeck, 1984, Andrews & Goodson, 1980). An interesting point for thought is how cognitive science can improve existing guidance. To do that cognitive scientists need to attend to that guidance.

Slide 2

Generalities about cognitive functioning

Components of theory

- Mental Representations
- Knowledge extensity, quality
- Meta-control processes
- Functional conditions
- Learning phases in skill development

Architecture

- Three kinds of memory
- Two main types of processing
- Knowledge compilation

I think there is general agreement about certain hypotheses. For instance, **mental representation** is an important concept. It is important because functionally it provides the individual with the basic schemas for organizing and interpreting a situation, along with appropriate actions. It also provides for learning by providing bases for acquiring new knowledge. Therefore, understanding both the mental structures needed for competent performance and a learner's existing representations is important for devising instruction. Next, the **extent and quality of knowledge** is important, not only for immediate performance, but for adapting and/or acquiring new knowledge. Self-monitoring mental processes or structures are important

for correction of performance and to maintain performance over time. These are sometimes called **meta-cognitive processes** and they are important to know for instruction. Finally, I think that the research and theorizing in cognitive science points to the importance of understanding the conditions under which performance and learning will occur. This is the context in which the learning and performing takes place, and its characteristics are important to identify for purposes of teaching and for promoting transfer.

Although the theory components and architecture are widely accepted, they provide only a very general scheme for controlling teaching processes. The analysis of competent performance and its development that must be done to plan instruction, must include cognitive organization and structures, and attend to the phases and processes involved in acquisition. This is, at least hopefully, an advance in perspective over the older "behavioristic" view that may have substantial positive effects on instruction.

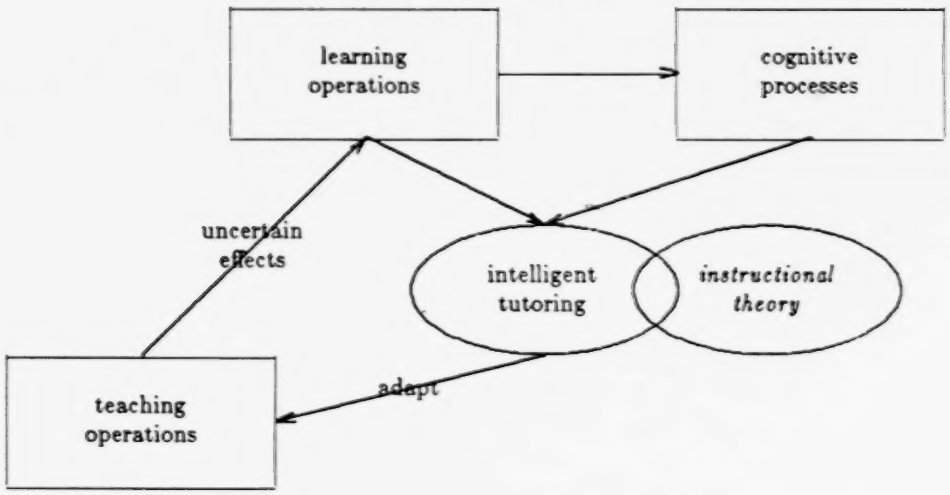
There are, however, two main issues that need attention. First, there is a logical issue mentioned earlier. Even when we have a precise description of the development of competence in a particular domain by student learning operations so that it can be modeled, our ability to control the teaching operations to bring about bring about those learning operations is tentative. Rules for instruction do not come directly from cognitive principles. The second issue derives from the first. Since instructional operations may imperfectly produce effects on student learning processes, it is necessary to monitor student processing more closely, and then adjust instruction appropriately to student understanding. Such control may be possible only with tutors or intelligent machines that tutor students (e.g., Collins & Stevens, 1983; Anderson, *et al*, 1984; Sleeman & Brown, 1982). This is the subject of Slide 3.

This slide shows that cognitive theory describes (and often models) the relation between knowledge, knowledge structures, mental processes and action. Given certain conditions, mental processes occur and the structure of knowledge is changed (learning). These analyses are often modeled precisely as computer programs to assess their accuracy. However, when attempting to generalize the conditions and state rules/prescriptions for instruction the relationship is more

Slide 3

Cognitive Theory & Prescriptions

- Cognitive theory describes relation
  - ▽ Knowledge, Thought & Action
  - ▽ Conditions, Processes Yield Learning (reliably)
- Derivative Application Rules
  - ▽ Instructional Arrangements Yield Learning (maybe)
- Relation Between Instructing & Student Processes May Need Automation



uncertain. This is due primarily to the lack of certainty about the effects of particular instructional actions. The mental processes may not occur reliably when the instruction is given. Other factors and variables can confound the situation. As a simple example, most cognitive models ignore student motivation, yet student interest might determine whether any attention is given to the instruction. Therefore, as shown in the diagram, automated tutors may be able to provide better control over the process by sensing learner processing and understanding and then adapting or modifying instruction appropriately. But, for broader application purposes a comprehensive instructional theory is needed.

3. Some Engineering Heuristics

In a paper discussing instructional theory, Snelbecker (1983) identifies two classes of people interested in such a theory: knowledge-producers, and knowledge-users. Most cognitive scientists would fall into the former class, and normally have little contact with attempts to put knowledge into practice. It seems likely that systematic examination by knowledge-producers of problems of application would provide opportunity for developing better theory as well as better use of current knowledge. In the following sections of the paper I will review briefly some selected advice for instruction from some cognitive theorists (e.g., Case, 1978, Collins & Stevens, 1983, Sebrechts, 1983, J. Anderson, *et al*, 1984, Schneider, 1985, N. Fredericksen, 1985, Scardamalia & Bereiter, 1985). These are often referred to as principles or rules for teaching, although I think of them as instructional engineering heuristics because of their tentative nature and incompleteness. For the most part these researchers ignore efforts to derive instructional theory and practical rules for application outside their own research domain (see Reigeluth, 1983 for a summary of several examples of these efforts, or Gagné & Briggs, 1979). I think that the usefulness of cognitive theory as a basis for instructional theory can be improved by the understanding of some of the problems of the implementation of the theory, and perhaps by examining some earlier attempts to derive rules (heuristics) for designing teaching operations. Therefore, following these examples, I will review an attempt to devise a scheme for guiding the development of vocational education that seems to anticipate many of the suggestions being made by cognitive scientists (Prosser & Quigley, 1949, Shoemaker, 1967). It may be that this scheme can be used generally for designing instruction, and that research can provide techniques to improve the process.

In addition to reviewing the guidance for instruction, I will point out that two major issues confront anyone making recommendations about how to carry out instruction. First, is the reliable effectiveness of the proposed principles. Evaluation of this reliability is not done often. Second, is how to get the knowledge users to learn and adapt their practices in designing and carrying out instruction. These are not usually concerns considered by cognitive researchers. They are, however, problems of human cognition themselves, and they are important for the

viability of the discipline. They should be considered.

Slide 4.1

Engineering Heuristics[1]

I.A. **Developing the correct strategy.**

- a.1 Provide some means for the student to assess the adequacy of his/her current strategy.
- a.2 Provide the student with a problem situation where the inadequacy of the current strategy can be seen.
- a.3 Provide a simple explanation for why the current strategy is inadequate.
- a.4 Provide a clear demonstration of the correct strategy.
- a.5 Provide a clear explanation of the reason(s) why the correct strategy works.
- a.6 Provide practice, coaching, and practice generalizing the strategy.

I.B **Minimizing memory load.**

- b.1 Minimize the number of items of information the student must attend to.
- b.2 Use familiar cues and require familiar responses.
- b.3 Insure that stimuli to be attended stand out from the context.

Taken from R. Case, (1978).

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[1] Reigeluth (1983), calls these **Formative Hypotheses**.

Slide 4.2

Engineering Heuristics (*continued*)

II.A **Inquiry teaching recommendations.**

Teacher Goals & Subgoals

1 Teach a general rule or theory.
   - A Debug incorrect hypotheses.
   - B Teach how to make predictions in novel cases.

2 Teach how to derive a general rule or theory.
   - A Teach what questions to ask.
   - B Teach what is the nature of the theory.
   - C Teach how to test a rule or theory.
   - D Teach students to verbalize and defend rules or theories.

II.B **Strategies for Inquiry Teaching.**

- A Select positive and negative exemplars.
- B Vary cases systematically.
- C Select counterexamples.
- D Generate hypothetical cases.
- E Have students form and test hypotheses.
- F Have students consider alternative hypotheses.
- G Entrap students to reveal misconceptions.
- H Trace consequences to a contradiction.
- I Get students to rely on own theory not authority.

Taken from Collins & Stevens (1983), pp. 258ff.

Slide 4.3

Engineering Heuristics (*continued*)

III. Cognitive guidelines for computer-based instruction.

A. **Interface**

- a.1 Make the interface with the computer transparent.
- a.2 Minimize input difficulty (typing, selection), time, location
- a.3 Little or no computer-specific learning required...no special terms, codes, language not in students' knowledge.

B. **Cognition**

- b.1 Maximize domain knowledge image.
- b.2 Minimize retention of non-target domain information. Allocate student's memory/attention resources to target domain and not to computer interface. The goal is to have no instruction required for using the computer.

From Sebrechts (1983).

Slide 4.4

Engineering Heuristics (*continued*)

IV.A **Cognitive principles in the design of computer tutors.**

- a.1 **Identify the goal structure of the problem space.** Goal structure communicated to student and provides structure for instruction.
- a.2 **Provide instruction in the problem-solving context.**
- a.3 **Provide immediate feedback on errors.**
- a.4 **Minimize working memory load.**
- a.5 **Represent the student as a production set.**
- a.6 **Adjust the grain size of instruction with learning.**
- a.7 **Enable the student to approach the target skill by successive approximation.**
- a.8 **Provide general problem solving rules, not analogies.**

Taken from Anderson, Boyle, Farrell, & Reiser (1984).

Slide 4.5

Engineering Heuristics (*continued*)

V.A **Guidelines for Training High Performance Skills**

a.1 **Fundamental proposition:** Human performance results from the interaction of two qualitatively different forms of processing: **automatic and controlled**.

a.2 **Macro-rule:** Training should develop automatic component skills to perform consistent task components, **and** develop strategies to allocate limited controlled processing resources to inconsistent or poorly developed task components.

Implementation Rules:

Rule 1: Present instruction to promote consistent processing by learner.

Rule 2: Provide many trials of critical skills, using simulation and time compression.

Rule 3: Don't overload working memory and minimize memory loss.

Rule 4: Vary aspects of the task that vary in the operational situation.

Rule 5: Maintain active participation throughout training by frequent testing.

Rule 6: Maintain high motivation throughout training period.

Rule 7: Present information that illustrates the context.

Rule 8: Intermix training of components to distribute practice and facilitate perceiving interrelationships of components.

Rule 9: Train under mild speed stress to improve learning rate.

Rule 10: Train strategies that minimize operator workload.

Rule 11: Train time-sharing skills for dealing with high-workload.

Taken from Schneider (1985).

Slide 4.6

Engineering Heuristics (*continued*)

VI.A **Suggestions for Instruction from Cognitive Research**[1]

- a.1 **Teach Cognitive Processes**
- a.2 **Teach Development of Problem Structure**
- a.3 **Teach Pattern Recognition**
- a.4 **Teach Problem Solving Procedures**
- a.5 **Teach the Knowledge Base**
- a.6 **Teach Development of Knowledge Structures**
- a.7 **Teach Aptitudes**
- a.8 **Provide Practice with Feedback**
- a.9 **Use Models to Teach Representation**

[1]N. Fredericksen (1985).

Slide 4.7

Engineering Heuristics (*continued*)

VII.A **Designing a procedural facilitation for composition**[1]

1 **Identify a self-regulatory function in experts that's not in students.**

2 **Describe it in terms of mental operations.**

3 **Devise cueing for the process that minimizes demand on mental resources.**

4 **Devise external supports/teaching to reduce information processing burden of the mental operations.**

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[1] Scardamalia & Bereiter (1985).

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4. Knowledge-user guidelines

Attempts at developing guidelines for instructional design based on "principles" of psychology and related disciplines have been made for many years. Because of limitations in the availability of psychologically trained personnel these guidelines were proceduralized and standardized in the military services (Montague, & Wulfeck 1986). All share a common approach based on instructional psychology (Glaser, 1976). Performance on job-tasks are analyzed, learning requirements are specified as objectives, assessment of learning is devised, and instruction is arranged within the existing resource constraints, and the resulting instruction is tried out and revised as needed. The procedures in recent guides are supposed to be prescriptive, and reduce the dependence on skill and knowledge of instructional and cognitive psychology. However, the procedures specify "what needs to be done to develop instruction," but not "how to do it." Thus users need to know not only the content to be taught, but must artistically interpret the heuristics recommended by research. The heuristics provided from cognitive researchers/theorists in Slide 4 have several things in common as summarized in Slide 5. All emphasize the need for analyzing the mental structures and processes involved in performing and learning. They suggest

that the domain context is an important context to use in the instructional environment. Analysis of the domain is important to identify which parts of the skills and knowledge require different forms of instruction. Memory and attention is limited, therefore, the memory load during training has to be adjusted to minimize the load on memory and insure learning. Implicit or explicit in the recommendations is the idea that common student errors need to be identified and used to key changes or elaborations of instructional presentations. Students make errors in new learning often because of old knowledge, or misconceptions. These need to be taken into account in designing instruction. Feedback to students, usually attempting to overcome errors, is a prevalent recommendation. Providing examples of approaches to learning problems and procedures with which to approach problems is common. Recommendations call for active student involvement in self-examination of their own performance.

Slide 5

Synthesis of Heuristics

- Systematic analysis of tasks
- Situational context
- Memory load
- Error analysis
- Feedback for errors
- Self-monitoring skill

Similar heuristics (they called them "principles") were proposed by Prosser & Quigley (1949) many years ago. Their advice seems consistent with the advice provided by cognitive research as just reviewed. Slide 6 represents my distillation of their principles. Notice the importance they placed on the replication of the working or performing environment for teaching. It becomes a schema for the instructional environment. Cognitive scientists emphasize the role of elaborate mental entities: frames, scripts, mental models, schemas, in organizing memory and in acquiring new knowledge (e.g., R. C. Anderson, 1977, Wilson & Anderson, 1986). Therefore, providing an understandable frame-of-reference or schema for a learning environment is an important

conception to guide instructional design. It is a schema for designers. Shoemaker, (1967), and Sticht, *et al* (1986) provided guidelines for "Functional Context Training" which is an approach to design that requires that the teaching environment be designed to represent the performing environment and be comprehensible to the students. Slide 7 provides recent guidelines on Functional Context Training from Sticht *et al.*

Slide 6

Heuristics for Vocational Education[1]

- Replicate working environment in instruction
  - --same operations
  - --same tools
  - --same machines
  - --same thinking & manipulations
- Adapt instruction to trainee
  - --intelligence, aptitudes
  - --interests
  - --prior knowledge
- Give frequent practice
  - --enough to develop skill
- Use "expert" teachers who know the job
  - --to design training
  - --to teach
- Be concerned with factors promoting job satisfaction
- Don't teach without sufficient resources

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[1] These heuristics were distilled from 16 principles proposed by Prosser & Quigley, (1949).

Replication of the performance context in instruction provides important and valuable context needed to promote transfer. It also makes it easier to implement the heuristic guidance. Whether done explicitly or not, it provides training about relevant cues, and timing needed to guide performance. Designing instructional presentations to reflect both the performance situation, and to be based on current student knowledge is a difficult chore, but it seems to almost automatically incorporate many of the recommendations from cognitive research. Where detailed guidance is lacking, for example, regarding how much practice is enough, the instructor can zero in on an amount empirically. Inspection of slides 4 & 5 and comparing the

recommendations with the functional context approach will reveal additional similarities.

Slide 7

Functional Context Approach

Functional context training: Goals for instruction.

a.1 Make the instruction as meaningful to the learner as possible in terms of the learner's prior knowledge. This makes it possible for learner to relate new information to that already possessed, or enable him/her to transform old knowledge into new knowledge.

a.2 As much as possible, use the materials and equipment that the learner will use after training or education as part of the instructional program. This motivates the learner by showing him/her the relevance of the learning, and promotes transfer.

Taken from Sticht, *et al*, (1986).

Course revision recommendations.

a.1 Develop a learning system that uses what the individual trainee already knows as the basis for training.

a.2 Relate learning situations and materials directly to the military.

a.3 Develop specific course terminal objectives that are job-relevant.

a.4 Identify precise learning requirements of courses and jobs, paying special attention to areas that might be especially difficult for less qualified personnel.

a.5 Delineate requirements for literacy training "...integrate needed literacy training into the skill training program or during off-duty hours."

Cited in Sticht, *et al*, 1986, from a letter to AF Air Training Command 21 December 1966 on: *Training programs for Project 100,000.*

My suggestion is that the functional context approach provides a schema which has advantages for knowledge-users and knowledge-providers alike. It provides a framework for the learning environment that is consistent with the recommendations for teaching from current cognitive research, and it provides workable guidance for those designing instruction. In regard to the latter point, it provides a useful model of the work environment that helps provide perspective for instantiating more detailed recommendations. The recent recommendations by Anderson *et al*, and Schneider, seem to me to provide refinement to the heuristic notions proposed by Prosser & Quigley. I would expect that if the approach were used for instructional design and evaluated systematically, research problems could be identified that could then be solved. Slide 8 summarizes some important advantages.

The tentative nature of the heuristics and the functional context schema points up the need to assess the reliability of derivative instructional manipulations. There is a constant need to demonstrate the effectiveness of instructional programs. Yet, in recent years, that sort of research has become infrequent.

Slide 8

Advantages of the Functional Context Approach

Provides default system for developing competence

—comprehensible learning environment
—maps into much of cognitive theory
—promotes transfer
—new research can provide refinement
—more research needed directed at
further refinement, automation of tutoring

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5. Mechanisms and Strategies for Application

Even though cognitive theory may not be fully formed, there seems to be sufficient belief in the generalities to provide guidance for instructional practice. Otherwise, we would not have the sorts of lists of application rules shown in Slide 4. Guides for helping design and develop instruction are plentiful (Andrews & Goodson, 1980; Montemerlo & Tennyson, 1976; Montague & Wulfeck, 1986). Although such guides are plentiful, they are not used well. Therefore, their effectiveness in guiding instructional design and development is attenuated. In the military, the guides are used by personnel who are (or may be) subject matter specialists, are assigned as instructors for a short period, and who have minimal training in teaching. In practice, the guides are complicated and long and require considerable effort in understanding the recommendations. So even if (presumably) more useful cognitive theory recommendations were included in the guides it seems unlikely that they would be used without improvement in the system in which they're used. I suspect that because the functional context approach provides a schema for instructional development it might improve instructional design. However, it too, would have to be learned and understood, and its effectiveness evaluated.

Slide 9

Recommendations for Application

- Adopt cognitive, functional context approach
- Provide simpler guides for knowledge users organized around the schema
- Train and monitor users
- Provide automated aids with heuristics built-in

The recommendations shown in slide 9 summarize the discussion. Adopting the functional context approach is advisable because it produces a learning environment consistent with many of the recommendations for instructing from cognitive research. There is then the problem of providing Guides to help instructors design the teaching environment and to provide training for them in using the Guides. Instructors will have to be trained better, and their design and development work monitored better. Guides which have been developed and used in the past have not been very effective. This may have been due to the lack of an adequate organizing framework. Whether or not the functional context approach can improve instructional design is an empirical question. It is likely that automated aids for design and development provide an important way to improve the application of the heuristics derived from research (Montague & Wulfeck 1984; Moran, 1986). They could provide intelligent advice and coaching for knowledge-users during design and development of instruction. It's worth a try.

6. Research needed to support the guidance

It is apparent from examining the heuristics recommended in slide 4, that our ability to provide detailed advice for designing instruction is wanting. For example, it is not possible to specify how much practice is needed to learn tasks so that those that ultimately will become automatic, can be learned "well enough" to guarantee their being remembered on the job and that their final skill levels can be attained. We can't advise about when and how often to test and provide feedback without interfering with learning. Therefore, programmatic research is needed to provide the details of the teaching process. In slide 10, I have listed a few examples of

research issues that could provide important information for teaching.

Slide 10

Research Issues Needed to Improve Guidance

- Analysis of tasks and dividing them
  - --part-task identification
  - --sequencing/intermixing
  - --fidelity to performance situation
- Amount of practice
  - --speeding acquisition
  - --level of competence
- Is forgetting important?
  - --better task design may help
- Procedures for feedback
  - --assessing prior knowledge
  - --when to test & give feedback?
  - --regularly or sensitive to learning?
- How many and type of examples?
- Identify "bugs"
  - --when to correct them
- Individual or collective training
- Transition from novice to expert
  - --development of competence

▽ Are these the same questions that Prosser & Quigley might have asked in 1949 or in 1925 when they first proposed their principles?

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